AD-A262 479

(2)

NASA
Technical Memorandum 105830

AVSCOM
Technical Report 92-C-007

Evaluation of an Oil-Debris Monitoring Device for Use in Helicopter Transmissions

David G. Lewicki
Propulsion Directorate
U.S. Army Aviation Systems Command
Lewis Research Center
Cleveland, Ohio

Donald M. Blanchette
Canadian National Defense Headquarters
Ottawa, Ontario, Canada

and

Gilles Biron
Quality Engineering Test Establishment
Hull, Quebec, Canada

August 1992

NASA

US ARMY AVIATION SYSTEMS COMMAND

EVALUATION OF AN OIL-DEBRIS MONITORING DEVICE FOR USE IN HELICOPTER TRANSMISSIONS

David G. Lewicki
Propulsion Directorate
U.S. Army Aviation Systems Command
NASA Lewis Research Center
Cleveland, Ohio

Donald M. Blanchette
Canadian National Defense Headquarters
Ottawa, Ontario, Canada

and

Gilles Biron
Quality Engineering Test Establishment
Hull, Quebec, Canada

SUMMARY

Experimental tests were performed on an OH-58A helicopter main-rotor transmission to evaluate an oil-debris monitoring device (ODMD). The tests were performed in the NASA 500-hp Helicopter Transmission Test Stand. Five endurance tests were run as part of a U.S. Navy/NASA/Army advanced lubricants program. The tests were run at 100-percent design speed, 117-percent design torque, and 121 °C (250 °F) oil inlet temperature. Each test lasted between 29 and 122 hr. The oils that were used conformed to MIL-L-23699 and DOD-L-85734 specifications. One test produced a massive sun-gear fatigue failure; another test produced a small spall on one sun-gear tooth; a third test produced a catastrophic planet-bearing cage failure. The ODMD results were compared with oil spectroscopy results. The capability of the ODMD to detect transmission component failures was not demonstrated. Two of the five tests produced large amounts of debris. For these two tests, two separate ODMD sensors failed, possibly because of prolonged exposure to relatively high oil temperatures. One test produced a small amount of debris and was not detected by the ODMD or by oil spectroscopy. In general, the ODMD results matched the oil spectroscopy results. The ODMD results were extremely sensitive to oil temperature and flow rate.

INTRODUCTION

Gear and bearing wear are common phenomena in rotating machinery. Excessive wear could be an indication of component failure, and its detection could be a valuable tool in diagnostics and prognostics. This is especially useful in aircraft applications, such as helicopter transmissions and engines, where safety and reliability are crucial. A common method of analyzing component wear is through oil-debris monitoring.

A variety of oil-debris monitoring techniques currently exist. Spectroscopy is a widely used technique that determines total content of wear metals such as iron, copper, silver, chromium, etc. (Beerbower, 1976). The presence of certain combinations of metals can provide valuable insight regarding the condition of components. The U.S. military have used spectroscopy for some time to detect impending failures of engines and gearboxes. However, spectroscopy requires rather expensive

instrumentation, must be performed off-line in a laboratory, and can only detect particles smaller than about 10 μm in size.

Ferrography is another common technique for determining wear particles of an oil sample (Cheiky-Zelina, 1991). This technique can determine size and shape of ferrous wear particles, but it must be performed off-line and requires sophisticated equipment as well as trained analysts. Lewis (1988) describes some specialized instrumentation being developed to measure metal wear. Here, an oil sample is passed through a filter of fine, magnetized fibers which collect the ferrous debris. The amount of debris captured is determined from an increase in magnetic flux of the filter.

A variety of on-line methods are available for oil debris monitoring. Some of the principles of the various methods are ultrasonics (Nemarich et al., 1988), surface layer activation (Blatchley and Sioshansi, 1988), and x rays (Pieper and Taylor, 1989). One of the most common monitoring devices is a quantitative debris monitor, in which ferrous debris is magnetically attracted to a sensor which produces electrical voltage output proportional to the mass of the debris (DiPasquale, 1988). This device can separate debris into large and small categories to aid in health monitoring evaluation, but it is restricted to particles greater than about 150 μm in size. Another similar device uses a magnet to trap particles and then uses inductance to measure particle concentration (Chambers et al., 1988; and Campbell, 1990). This unit can measure particles from 1 to 1000 μm.

A cooperative program between the NASA Lewis Research Center, the U.S. Army Propulsion Directorate, and the Canadian Department of National Defense was established to evaluate an on-line, oil-debris monitoring device (ODMD) for a helicopter transmission application. An ODMD was installed in the NASA 500-hp Helicopter Transmission Test Stand. The main-rotor transmission of an OH-58A helicopter was tested. A number of endurance tests were performed which produced transmission component failures. A description of the test hardware and test stand, the ODMD, the testing procedure, and the results of the tests are presented.

APPARATUS

Main-Rotor Transmission of OH-58A Helicopter

The OH-58A is a single-engine, land-based, light, observation helicopter. The military version of this helicopter is the OH-58 Kiowa, and the commercial version is the 206 Jet Ranger. The design maximum input torque for the OH-58A main-rotor transmission (fig. 1) is 350 N-m (3100 in.-lb), and the design maximum input speed is 6060 rpm (Warren and Young, 1969). This corresponds to a design maximum power rating of 222 kW (298 hp). The transmission is a two-stage reduction gearbox with an overall reduction ratio of 17.44:1. The first stage is a spiral bevel gear set with a 19-tooth pinion that meshes with a 71-tooth gear. Triplex ball bearings and one roller bearing support the bevel pinion shaft. Duplex ball bearings and one roller bearing support the bevel gear shaft in an overhung configuration.

A planetary mesh provides the second reduction stage. The bevel gear shaft is splined to a sun gear shaft. Both a three-planet system (OH-58A) and four-planet system (OH-58C) were used for the tests. For the three-planet assembly, the 27-tooth sun gear drives three 35-tooth planet gears. The planet gears mesh with a 99-tooth fixed ring gear splined to the transmission housing. The planet gears are supported by double-row spherical roller bearings attached to the planet carrier. Power is taken out through the planet carrier splined to the output mast shaft. The output shaft is supported at the top by a split-inner-race ball bearing, and at the bottom by a roller bearing. The four-planet

assembly differs from the three-planet assembly in that it has one more planet, the planet bearings are cylindrical rollers rather than spherical, and the planets are straddle mounted by the carrier rather than overhung. The four-planet assembly has significantly higher load-carrying capacity than that of the three-planet assembly.

The 71-tooth bevel gear also drives a 27-tooth accessory gear. The accessory gear runs an oil pump, which supplies lubrication through jets and passageways located in the transmission housing.

NASA Lewis 500-hp Helicopter Transmission Test Stand

The OH-58A transmission was tested in the NASA Lewis 500-hp Helicopter Transmission Test Stand (fig. 2). The test stand operates on the closed-loop, or torque-regenerative, principle. Mechanical power circulates through a closed loop of gears and shafts, one of which is the test transmission. The output of the test transmission attaches to the bevel gearbox, whose output shaft passes through a hollow shaft in the closing-end gearbox and connects to the differential gearbox. The output of the differential attaches to the hollow shaft in the closing-end gearbox. The output of the closing-end gearbox connects to the input of the test transmission, thereby closing the loop.

A 149-kW (200-hp), variable-speed, direct-current (dc) motor powers the test stand and controls the speed. The motor output attaches to the closing-end gearbox. Since power circulates around the loop, the motor replenishes only friction losses. An 11-kW (15-hp) dc motor provides the torque in the closed loop through use of the differential gearbox and chain drive. A mast-shaft loading system in the test stand simulates rotor loads imposed on the OH-58A transmission output mast shaft. Two vertical and one horizontal high-pressure nitrogen load cylinders provide lift and shear forces.

The test transmission input and output shafts have speed sensors, torquemeters, and sliprings. All three load cylinders on the mast yoke are mounted to load cells. The test transmission internal oil pump supplies lubrication. An external oil-water heat exchanger cools the test transmission oil. The 149-kW (200-hp) motor has a speed sensor and a torquemeter. The magnetic particle clutch has speed sensors and thermocouples on the input and output shafts. A facility oil-pumping and cooling system lubricates the differential gearbox, the closing-end gearbox, and the bevel gearbox. The facility gearboxes have accelerometers, thermocouples, and chip detectors for health and condition monitoring.

Oil-Debris Monitoring Device

The oil-debris monitoring device (ODMD) tested consists of a sensing coil, trapping magnet, and microcontroller. As oil passes through the sensing coil, the trapping magnet is repeatedly energized and de-energized. When energized, ferromagnetic debris is collected along the sensing coil. The sensing coil is the inductive component of a radio frequency oscillator. As debris is collected on the coil, the inductance increases and the oscillator frequency decreases. The ratio of the frequency change to trapping time interval is proportional to the bulk concentration of ferromagnetic debris. A more detailed description of the unit is given by Chambers et al. (1988) and Campbell (1990).

The ODMD was installed in the OH-58A transmission oil system (fig. 3). An adapter block was installed such that the oil flowing through the ODMD was after the pump but before the filter. A valve was installed to collect oil samples for spectroscopy analysis. A schematic of the lubrication system is given in figure 4.

TESTING PROCEDURE

The tests performed were part of a U.S. Navy/NASA/Army advanced lubricants program for helicopter transmissions (Lewicki, Decker, and Shimski, 1992). The goal was to develop a testing procedure to produce certain component failures in the OH-58A transmission while using a MIL-L-23699 base reference lubricant, then to run identical tests with advanced lubricants and demonstrate improved performance. The ODMD was installed during these tests to evaluate its failure detection capability. Five endurance tests (table I) were performed.

Since the 500-hp test stand is not equipped to operate unmanned, the tests were run about 8 hr each day and continued until the maximum run time was reached or until a failure was detected. Each day, the ODMD was turned on when the transmission reached full operating conditions of speed, torque, and oil temperature (this took about 30 min.). The ODMD remained on for the day, and the data was collected by a personal computer. At the end of each day's run, about a 1-ounce oil sample was collected and later was analyzed by spectroscopy.

RESULTS AND DISCUSSION

Test 1 was a 29-hr endurance run with the goal of producing sun gear fatigue, spiral bevel scoring, and mast-shaft ball bearing micropitting failures. The transmission was run at 100-percent design speed, 117-percent design torque, and 121 °C (250 °F) oil inlet temperature. The lubricant conformed to MIL-L-23699 specifications. The test produced a small pit on one sun gear tooth (fig. 5). This was discovered during an overhaul of the transmission. The results from the ODMD are shown in figure 6. The FE1 parameter indicates mass content of larger ferrous wear particles, and the FE2 parameter indicates content of particles from 1 to 1000 μm. The ODMD output had a few spikes in the data, but generally it produced a signal that indicated low ferrous content in the oil. The correlation between exact values of FE1/FE2 and component failures is not know at this time, and it is a function of component design, operating conditions, and oil filtration. In a previous engine study, an FE2 value of 800 Hz/sec corresponded to an iron concentration of 8 ppm, which was within the normal range of wear. The ODMD output was sensitive to oil flow rate and temperature. The oscillation of the output was primarily a result of the oil temperature varying about 1 to 3 °C (2 to 5 °F). A spectroscopy analysis of the oil samples also indicated low ferrous content (fig. 6(c)). In summary, the failure from this test produced an extremely small amount of debris and was not detected by the ODMD or by spectroscopy.

Test 2 was a 122-hr endurance run with the goal of producing spiral bevel scoring and mast-shaft ball bearing micropitting failures. The operating conditions were the same as for test 1, but with reduced oil flow to the spiral bevel mesh. This test did not produce any component failures. The ODMD and spectroscopy results again indicated low ferrous content in the oil (fig. 7). The spectroscopy results indicated that the oil contained some debris at the start of the tests and then gradually cleaned itself during the run. This is not uncommon, because debris might have been left in the passageways from the previous run or might have been introduced in the transmission during build-up. The ODMD results generally agreed with the spectroscopy results showing some activity at the start of the run and then remaining constant for the rest of the test.

Test 3 was a similar endurance run with the goal of producing planetary fatigue, spiral bevel scoring, and mast-shaft ball bearing micropitting failures. A second brand of oil conforming to MIL-L-23699 specifications was used. The test was concluded at 88 hr because of a transmission chip detector light indication. At this time, the sun gear had a large number of spalls on many of its teeth

(fig. 8). The ODMD results (figs. 9(a) and (b)) were rather disappointing. About midway through the tests, the ODMD had extremely high activity, which would indicate component failure. As it turned out, the sensing unit itself failed and gave erroneous readings, even with no oil flowing through the sensor. The spectroscopy results (fig. 9(c)) were also rather strange. Even with the large amount of spalls and debris, the spectroscopy indicated an extremely clean oil. Further oil analysis using ferrography was performed. The results supported the spectroscopy, because little or no wear particles were observed on the ferrograms. An explanation could be that the amount of oil used for the samples (1 oz) or the sampling time (about every 8 hr) was not adequate to capture any meaningful debris from the gear tooth spall. A significant amount of debris was noticed both in the transmission and in the filter during overhaul.

Test 4 was a 114-hour endurance run with the goal of producing planetary fatigue, spiral bevel scoring, and mast-shaft ball bearing micropitting failures. A lubricant conforming to DOD-L-85734 specifications was used (this is basically a MIL-L-23699 specification oil with additives for improved load-carrying capacity). A new ODMD sensing unit was installed. As with test 2, no component failures were produced. The spectroscopy indicated an initial containment of debris, a quick cleaning of the oil, then a gradual increase of debris as the test progressed (fig. 10). The ODMD indicated activity at the end of the test, which supported the spectroscopy results. However, no significant component wear was apparent during inspection of the transmission after the test.

Test 5 was a repeat of test 3 with the goal of producing planetary fatigue, spiral bevel scoring, and mast-shaft ball bearing micropitting failures by using the second brand of oil conforming to MIL-L-23699 specifications. At 91 hr, a drastic increase in transmission heat generation was noticed from oil and component temperatures. At this point, the test was stopped. Overhaul of the transmission revealed that a planet bearing cage was completely destroyed (fig. 11). Unfortunately, the ODMD sensor failed and gave erroneous results after about 20 hr (fig. 12). This was the second failed sensor. No spectroscopy was performed, because the ODMD sensor failed during the initial part of the test. It is possible that the prolonged exposure to the relatively high oil temperature of 121 °C (250 °F) contributed to the sensor failures.

SUMMARY OF RESULTS

An oil-debris monitoring device (ODMD) was installed in an OH-58A helicopter main-rotor transmission in the NASA 500-hp Helicopter Transmission Test Stand. Endurance tests were performed as part of a U.S. Navy/NASA/Army advanced lubricants program. Five tests were performed. Two produced sun gear fatigue spalls, and one produced a planet bearing cage failure. The following results were obtained:

1. The capability of the ODMD to detect transmission component failures was not demonstrated.

2. Two of the tests produced large amounts of debris. The first was a sun gear fatigue failure; the second was a planet bearing cage failure. For these tests, two separate ODMD sensors failed, possibly because of prolonged exposure to a relatively high transmission oil inlet temperature of 121 °C (250 °F).

3. One test produced a small spall on one of the sun gear teeth, and was not detected by the ODMD or oil spectroscopy.

4. When the ODMD worked, its results matched those of the oil spectroscopy analysis.

5. The ODMD results were extremely sensitive to oil temperature and flow rate.

REFERENCES

Blatchley, C.C.; and Sioshansi, P.: On-Line Wear Monitoring in Bearings and Gears: Measurements Using Radionuclide Markers. Detection, Diagnosis and Prognosis of Rotating Machinery to Improve Reliability, Maintainability and Readiness through the Application of New and Innovative Techniques: Proceedings of the 41st Meeting of the Mechanical Failures Prevention Group, T.R. Shives and L.J. Mertaugh, eds., Cambridge University Press, New York, 1988, pp. 82-91.

Beerbower, A.: Spectrometry and Other Analysis Tools for Failure Prognosis. Lubr. Eng., vol. 32, no. 6, 1976, pp. 285-293.

Campbell, P.: On-Line Monitoring of Ferromagnetic Debris Concentration. Current Practices and Trends in Mechanical Failure Prevention: Proceedings of the 44th Meeting of the Mechanical Failures Prevention Group, H.C. Pusey and S.C. Pusey, eds., Vibration Institute, Willowbrook, IL, 1990, pp. 131-139.

Chambers, K.W. et al.: An Intelligent Sensor System for Equipment Health Monitoring of Ferromagnetic Wear Debris Concentration in Fluids. Engine Condition Monitoring: Technology and Experience, AGARD CP-448, 1988.

Cheiky-Zelina, M.: Ferrography: A Successful Preventive Maintenance Program for Gearboxes. Proceedings of the 3rd International Machinery Monitoring and Diagnostic Conference, Society for Experimental Mechanics, Inc., Bethel, CT, 1991, pp. 9-13.

DiPasquale, F.: Field Experience with Quantitative Debris Monitoring. Aircraft Gas Turbine Engine Monitoring Systems: An Update, SAE, Warrendale, PA, 1988, pp. 113-120 (Also, SAE Paper 871736, 1987).

Lewicki, D.G.; Decker, H.J.; and Shimski, J.T.: Development of a Full-Scale Transmission Testing Procedure to Evaluate Advanced Lubricants. To be published as NASA TP-3265, 1992.

Lewis, R.T.: The Wear Particle Analyzer. Detection, Diagnosis and Prognosis of Rotating Machinery to Improve Reliability, Maintainability and Readiness through the Application of New and Innovative Techniques: Proceedings of the 41st Meeting of the Mechanical Failures Prevention Group, T.R. Shives and L.J. Mertaugh, eds., Cambridge University Press, New York, 1988, pp. 72-81.

Nemarich, C.P. et al.: Evaluation of an On-Line Ultrasonic Particle Sensor Using Bearing Test Data. Detection, Diagnosis and Prognosis of Rotating Machinery to Improve Reliability, Maintainability and Readiness through the Application of New and Innovative Techniques: Proceedings of the 41st Meeting of the Mechanical Failures Prevention Group, T.R. Shives and L.J. Mertaugh, eds., Cambridge University Press, New York, 1988, pp. 72-81.

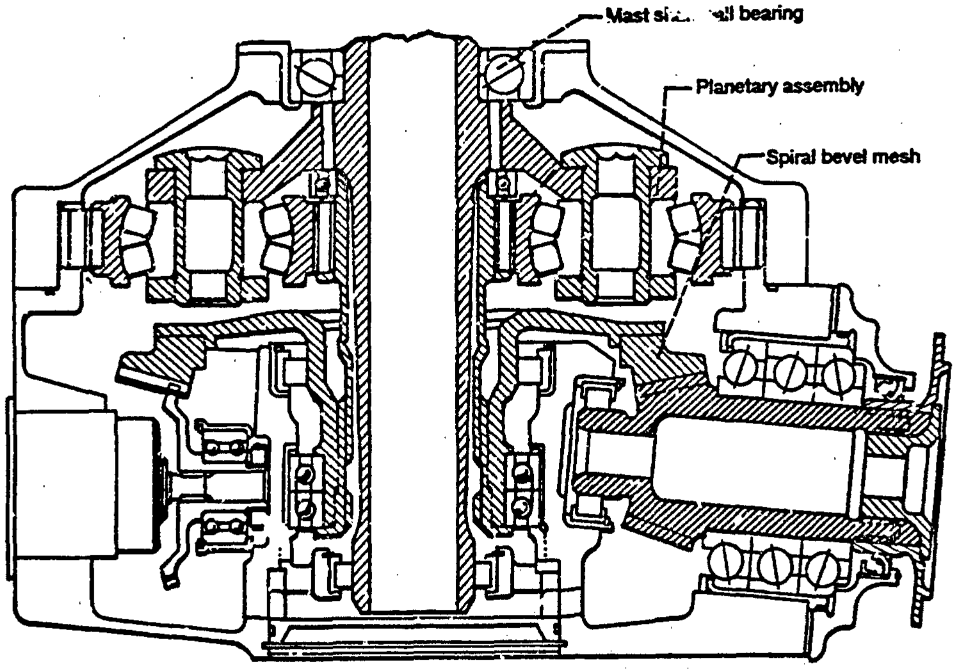
Pieper, K.; and Taylor, I.J.: In-Line Wear Monitor. Wright Research and Development Center Report No. WRDC-TR-89-2118, contract no. F33615-85-C-2537, General Motors Corp., Indianapolis, IN, 1989.

Warren, N.; and Young, J.: Transmission System Stress Analysis of the Model 206A-1/OH-58A Helicopter. Bell Helicopter Co. Report no. 206-099-119, 1969.

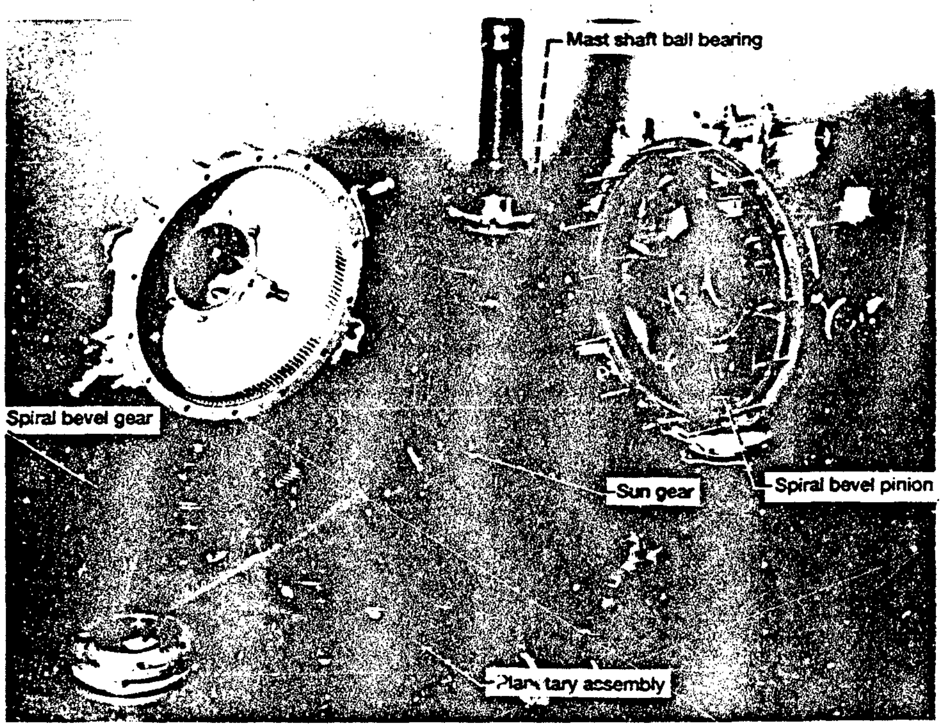
TABLE I.—TEST OPERATING CONDITIONS

[Transmission input speed, 6060 rpm - 100% design max; input torque, 410 N-m (3625 in.-lb) - 117% design max; oil inlet temperature, 121 °C (250 °F).]

Test	Time, hr	Mast radial load, percent of design max	Oil type	Oil flow rate to spiral bevel gear mesh, percent	Other conditions	Results
1	29	110	MIL-L-23699 Brand A	40	4-Planet gear system	Small spall on sun gear tooth
2	122	132	MIL-L-23699 Brand A	21	Reduced oil level; 4-planet gear system	No component failure
3	88	110	MIL-L-23699 Brand B	21	Reduced oil level	Spalls on sun gear teeth
4	114	110	DOD-L-85734	21	Reduced oil level	No component failures
5	91	110	MIL-L-23699 Brand B	21	Reduced oil level	Planet bearing cage failure



(a) Cross-sectional schematic.



(b) Disassembled view.

Figure 1. — OH-58A helicopter main rotor transmission.

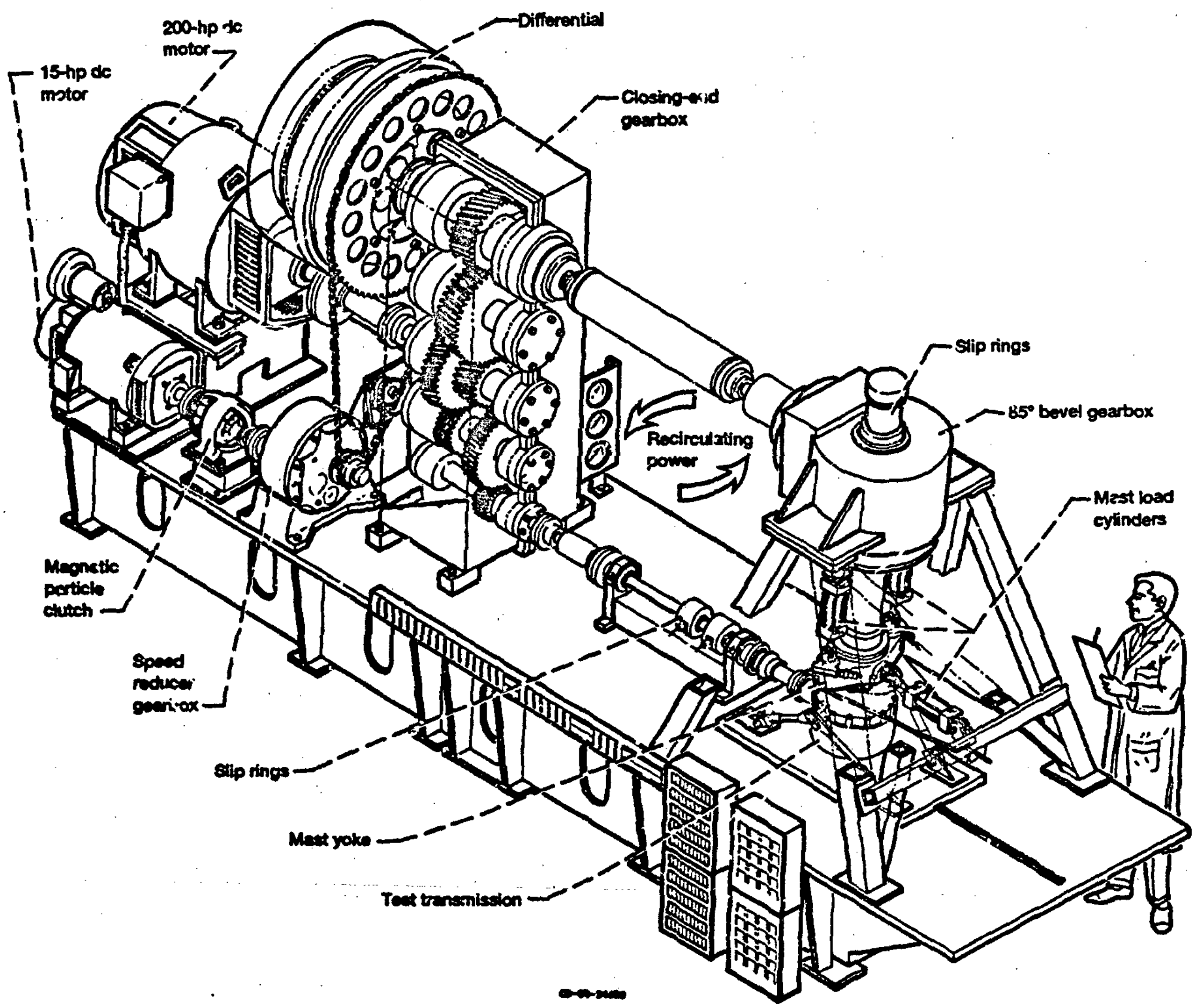
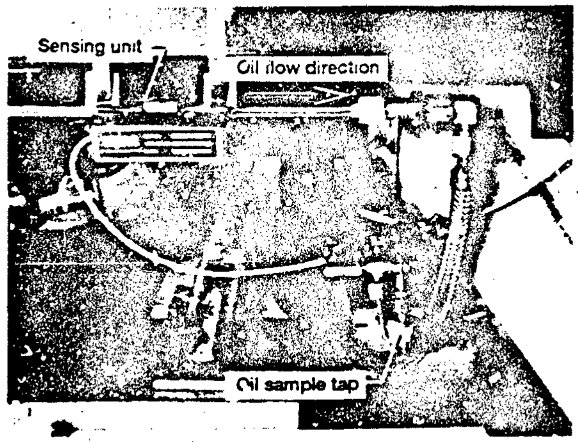
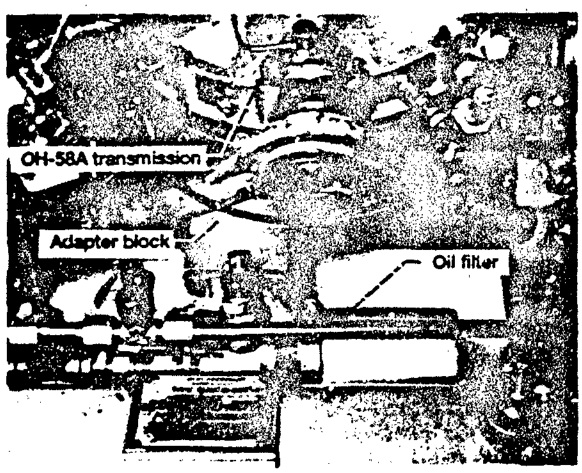


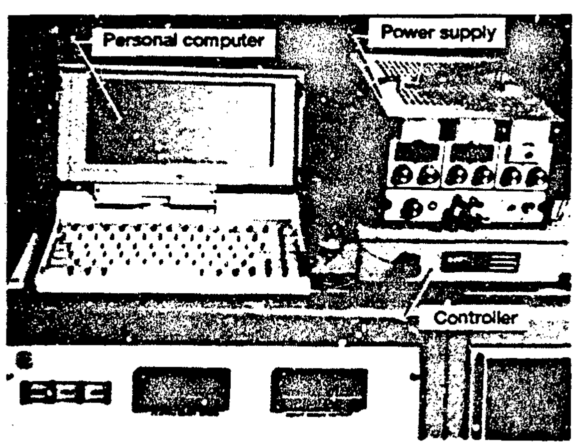
Figure 2. — NASA Lewis 500-hp helicopter transmission test stand.



(a) Side view.



(b) Top view.



(c) Controller.

Figure 3. — Oil-debris monitoring device installation in NASA Lewis 500-hp helicopter transmission test stand.

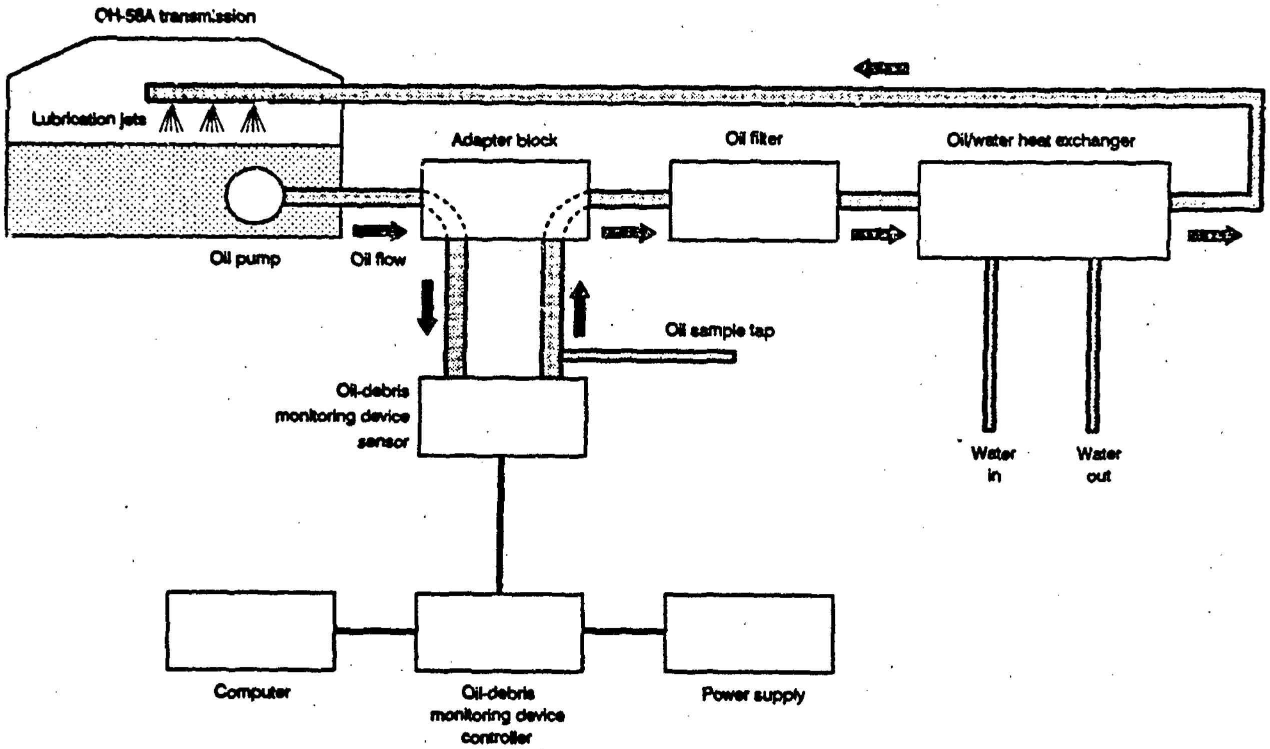


Figure 4. — Transmission lubrication system with oil-debris monitoring device installed.

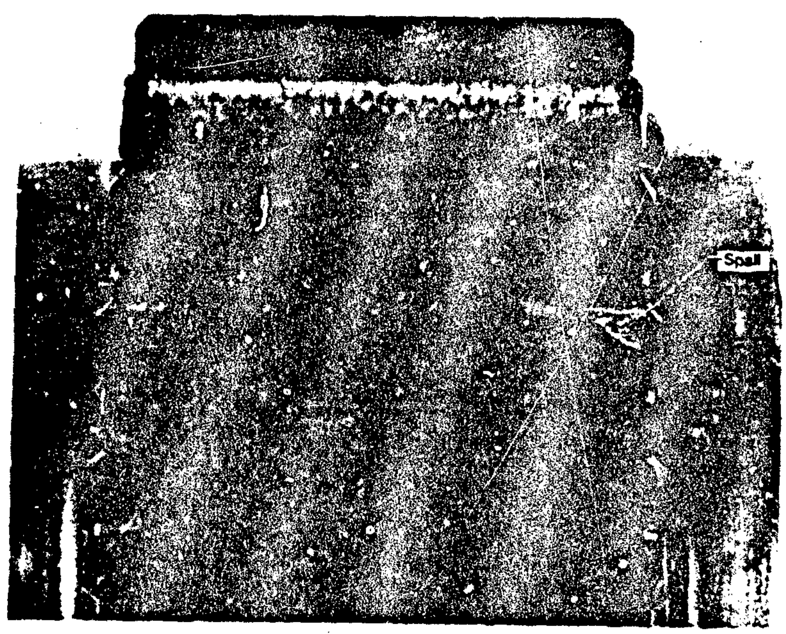


Figure 5. — Spall on sun gear tooth after test 1.

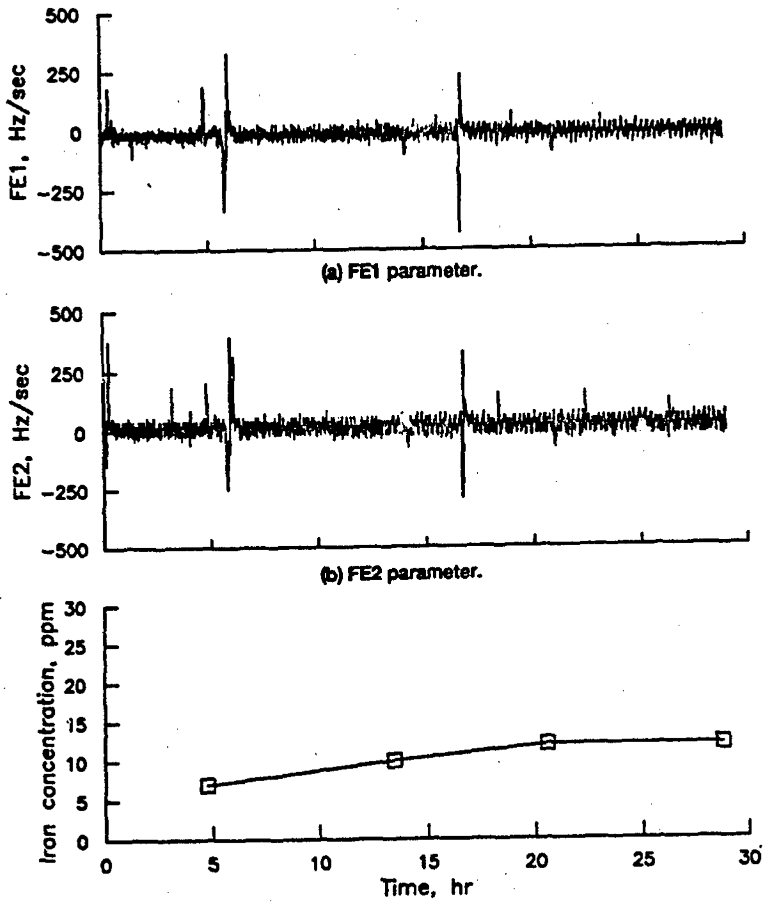
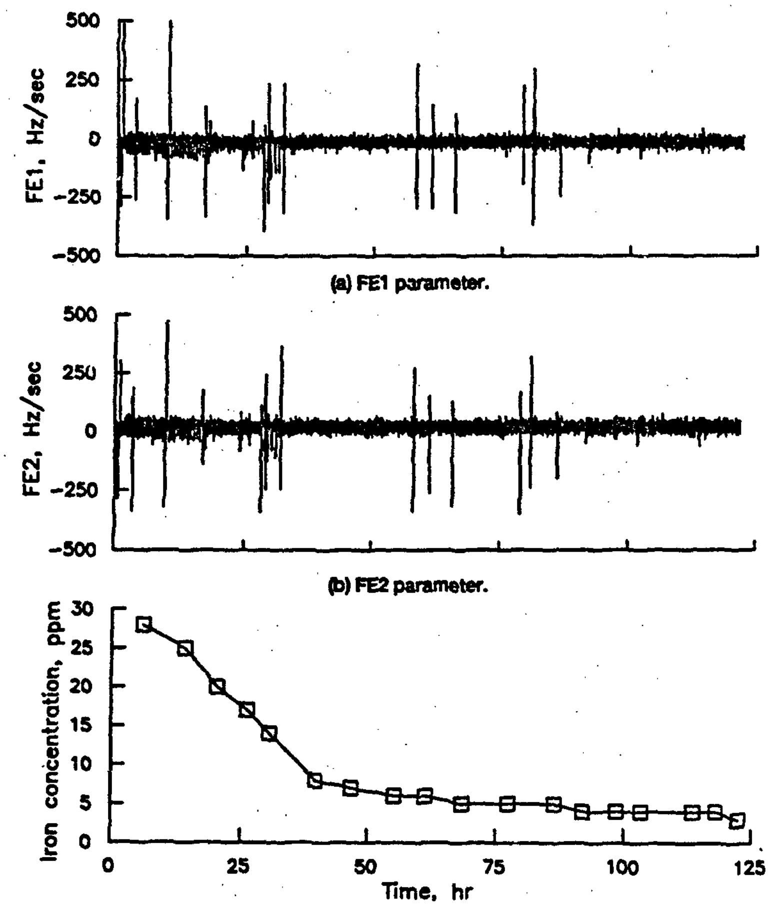


Figure 6. — Test 1 results; small spall evident on sun gear tooth after 29 hours.



(a) FE1 parameter.

(b) FE2 parameter.

(c) Spectroscopy results.

Figure 7. — Test 2 results; no component failure after 122 hours.

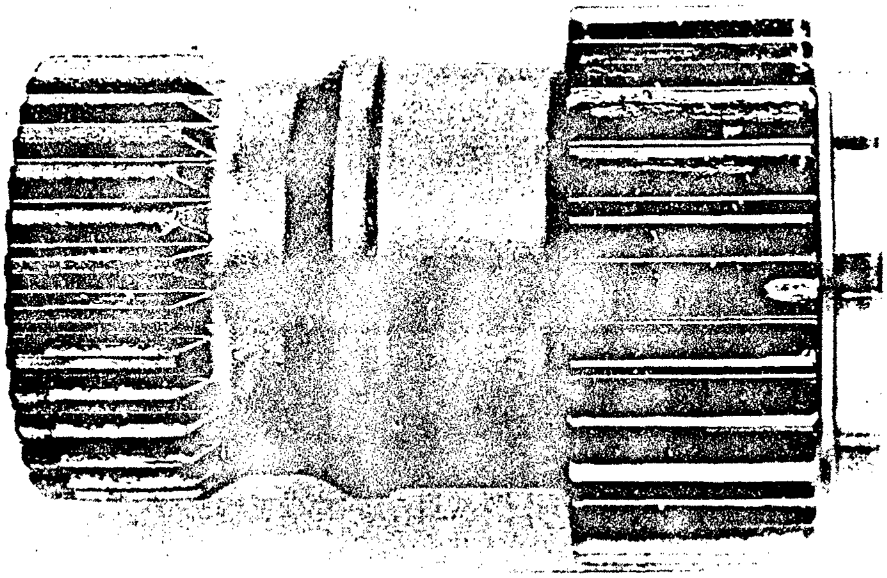


Figure 8. — Spalls on sun gear teeth after test 3.

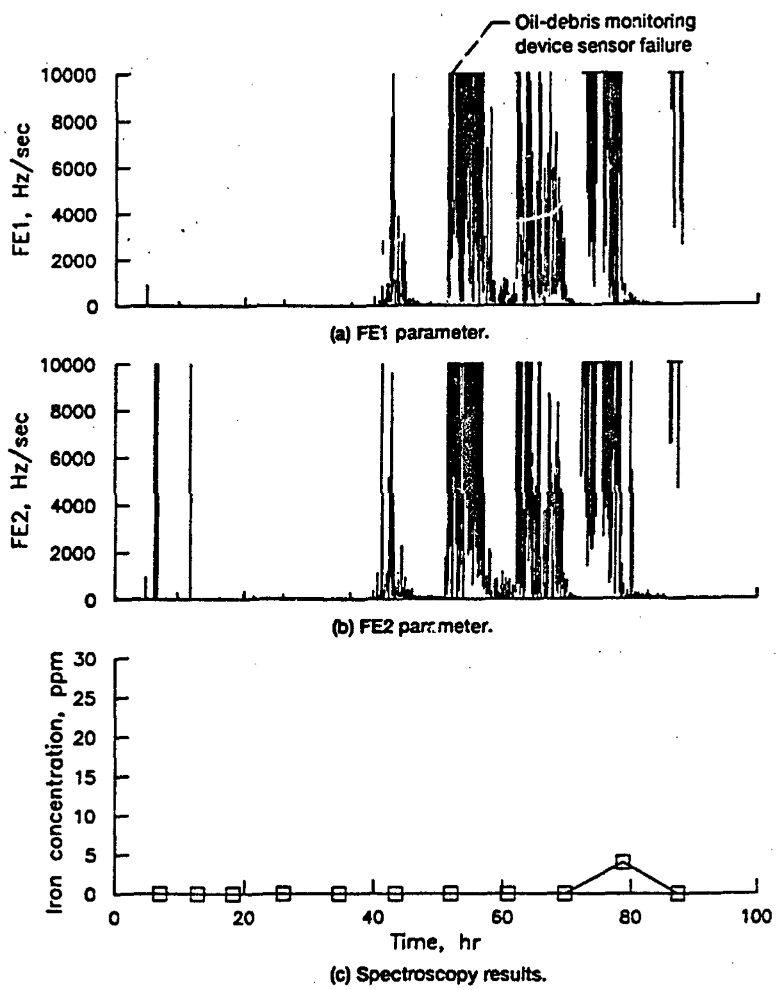
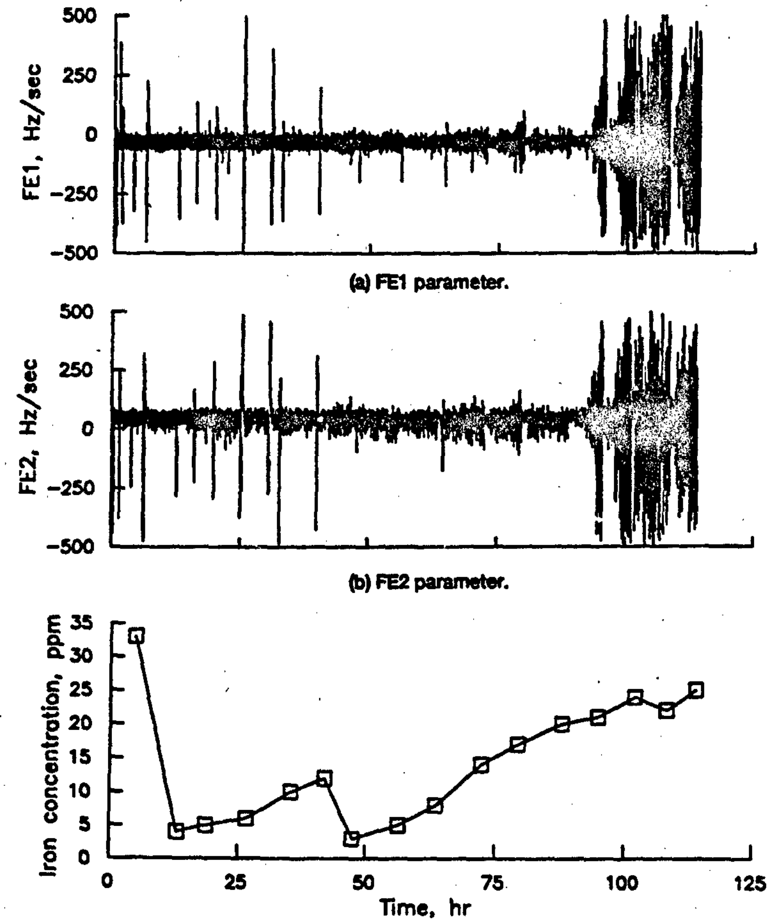


Figure 9. — Test 3 results; spalls evident on sun gear teeth after 88 hours.



(a) FE1 parameter.

(b) FE2 parameter.

(c) Spectroscopy results.

Figure 10. — Test 4 results; no component failure after 114 hours.

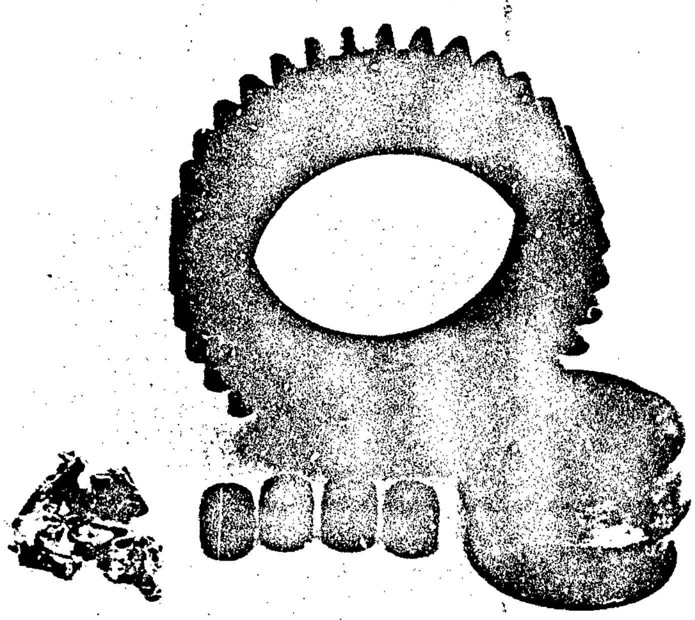


Figure 11. — Planet bearing cage failure after test 5.

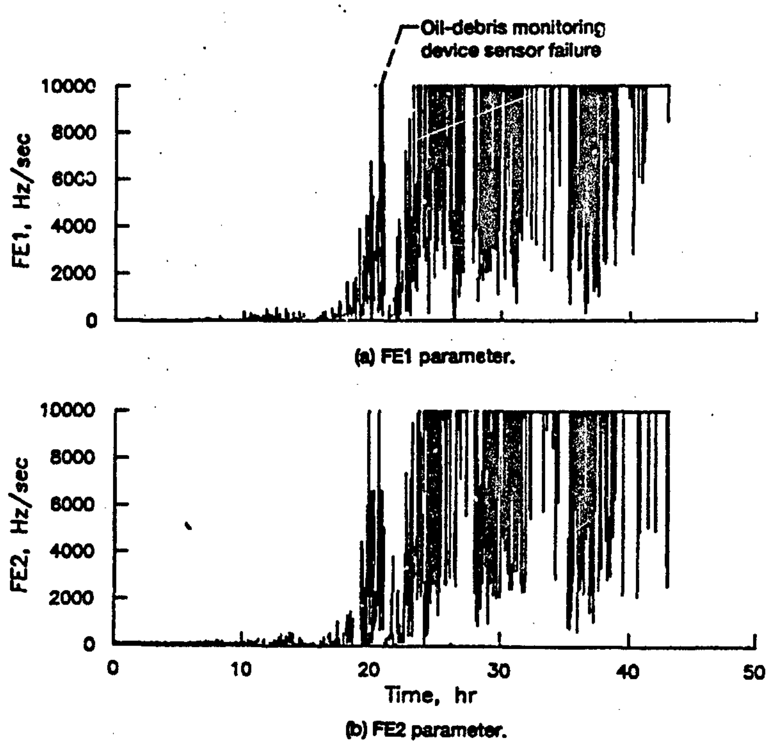


Figure 12. — Test 5 results; planet bearing cage failure at 91 hours.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
August 1992

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Evaluation of an Oil-Debris Monitoring Device for Use in Helicopter Transmissions

5. FUNDING NUMBERS
WU-505-63-36
1L162211A47A

6. AUTHOR(S)
David G. Lewicki, Donald M. Blanchette, and Gilles Biron

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Lewis Research Center
Cleveland, Ohio 44135–3191
and
Propulsion Directorate
U.S. Army Aviation Systems Command
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E–7265

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546–0001
and
U.S. Army Aviation Systems Command
St. Louis, Mo. 63120–1798

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM–105830

11. SUPPLEMENTARY NOTES
David G. Lewicki, Propulsion Directorate, U.S. Army Aviation Systems Command; Donald M. Blanchette, Canadian National Defense Headquarters, Ottawa, Ontario, Canada; and Gilles Biron, Quality Engineering Test Establishment, Hull, Quebec, Canada. Responsible person, David G. Lewicki, (216) 433–3970.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 37

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Experimental tests were performed on an OH–58A helicopter main-rotor transmission to evaluate an oil-debris monitoring device (ODMD). The tests were performed in the NASA 500-hp Helicopter Transmission Test Stand. Five endurance tests were run as part of a U.S. Navy/NASA/Army advanced lubricants program. The tests were run at 100-percent design speed, 117-percent design torque, and 121 °C (250 °F) oil inlet temperature. Each test lasted between 29 and 122 hr. The oils that were used conformed to MIL–L–23699 and DOD–L–85734 specifications. One test produced a massive sun-gear fatigue failure; another test produced a small spall on one sun-gear tooth; a third test produced a catastrophic planet-bearing cage failure. The ODMD results were compared with oil spectroscopy results. The capability of the ODMD to detect transmission component failures was not demonstrated. Two of the five tests produced large amounts of debris. For these two tests, two separate ODMD sensors failed, possibly because of prolonged exposure to relatively high oil temperatures. One test produced a small amount of debris and was not detected by the ODMD or by oil spectroscopy. In general, the ODMD results matched the oil spectroscopy results. The ODMD results were extremely sensitive to oil temperature and flow rate.

14. SUBJECT TERMS
Transmissions (machine elements); Gears; Bearings; Debris; Lubrication systems

15. NUMBER OF PAGES
20

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

END

FILMED

DATE: 4-93

DTIC